

Quantum computation and the physical computation level of biological information processing

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Abstract

On the basis of introspective analysis, we establish a crucial requirement for the physical computation basis of consciousness: it should allow processing a significant amount of information together at the same time. Classical computation does not satisfy the requirement. At the fundamental physical level, it is a network of two body interactions, each the input-output transformation of a universal Boolean gate. Thus, it cannot process together at the same time more than the three bit input of this gate – many such gates in parallel do not count since the information is not processed together. Quantum computation satisfies the requirement. At the light of our recent explanation of the speed up, quantum measurement of the solution of the problem is analogous to a many body interaction between the parts of a perfect classical machine, whose mechanical constraints represent the problem to be solved. The many body interaction satisfies all the constraints together at the same time, producing the solution in one shot. This shades light on the physical computation level of the theories that place consciousness in quantum measurement and explains how informations coming from disparate sensorial channels come together in the unity of subjective experience. The fact that the fundamental mechanism of consciousness is the same of the quantum speed up, gives quantum consciousness a potentially enormous evolutionary advantage.

1 Introduction

On the basis of the introspective analysis of visual perception, we establish a crucial requirement for the physical computation basis of consciousness. In this moment I see the meeting room, the audience, the chairs, a lot of things "together at the same time". This is an intuitive statement we cannot easily do without. I do not see the audience and the chairs at different times. Consciousness concerns the present time. I certainly see the audience and the chairs together and at the same time. We translate this statement into the language

of information theory. Seeing implies recognizing, thus processing. Therefore the physical computation basis of consciousness should allow processing a significant amount of information (at least that of a digital picture) together at the same time. We translate "together" into impossibility of breaking down the information processing into independent processings and assume that "at the same time" is to be understood in a non-relativistic framework.

We compare classical and quantum computation with the requirement.

At the fundamental physical level, classical computation is represented by a network of two body interactions, each the input-output transformation of a universal Boolean gate. The maximum amount of information processed together at the same time, occurring in the instant of the collision between two bodies, is the three bit input of the above gate. Many such gates in parallel do not count since the information is not processed together.

Quantum computation is examined at the light of our recent explanation of the "quantum speed up" (quantum algorithms requiring less computations than classical algorithms). Because of retrocausation, 50% of the information about the solution of the problem, acquired by measuring the content of the computer register at the end of the algorithm, goes back in time to before running the algorithm. The quantum algorithm uses this information to compute the solution with a lower number of operations. It is a superposition of causal/local computation histories, each corresponding to a possible way of getting in advance 50% of the information about the solution.

This retrocausation mechanism has an idealized classical analog, useful to compare quantum computation with the requirement. The quantum measurement that produces the solution is analogous to a many body interaction between the parts of a perfect classical machine. The classical representation of quantum retrocausation and nonlocality requires perfect machine rigidity, accuracy, and reversibility. The mechanical constraints of this machine represent the logical constraints of the problem to be solved. The many body interaction senses and satisfies all the constraints together at the same time, producing the solution in one shot. In contrast, classical computation, processing at most three bits at the same time, cannot take into account all the problem constraints at the same time; this leads to trial and error and to the relative zero of the quantum speed up.

Summing up, quantum computation satisfies the requirement of the physical computation basis of consciousness, which turns out to be the prerequisite of the quantum speed up. This shades light on the physical computation level of the theories that place consciousness in quantum measurement and explains how informations coming from disparate sensorial channels come together in the unity of subjective experience. The fact that the fundamental mechanism of consciousness is the same of the quantum speed up, gives quantum consciousness a potentially enormous evolutionary advantage.

In the following, after reviewing the quantum database search algorithm, we provide its many body representation. Then we show that the explanation of the speed up interplays with a variety of scientific and philosophical issues concerning consciousness and, more in general, biological information processing.

2 Reviewing Grover's algorithm

We review Grover's quantum data base search algorithm in the simple instance of data base size $N = 4$. For the sake of interdisciplinarity, we explain Grover's algorithm from scratch, without requiring any previous knowledge of quantum computer science. Data base search is seen as a game between two players. We have a chest of 4 drawers numbered 00, 01, 10, 11, a ball, and the two players. The oracle hides the ball in drawer number $\mathbf{k} \equiv k_0, k_1$ and gives to the second player the chest of drawers, represented by a black box that, given in input a drawer number $\mathbf{x} \equiv x_0, x_1$, computes the Kronecker function $f_{\mathbf{k}}(\mathbf{x}) = \delta(\mathbf{k}, \mathbf{x})$ (1 if $\mathbf{k} = \mathbf{x}$, 0 otherwise). The second player – the algorithm – should find the number of the drawer with the ball, and this is done by computing $\delta(\mathbf{k}, \mathbf{x})$ for different values of \mathbf{x} – by opening different drawers. A classical algorithm requires 2.25 computations of $\delta(\mathbf{k}, \mathbf{x})$ on average, 3 computations if one wants to be a priori certain of finding the solution. The quantum algorithm yields the solution with certainty with just one computation.

In our representation of the quantum algorithm, the computer has three registers. A two-qubit register K contains the oracle's choice of the value of \mathbf{k} . The state $|00\rangle_K$, or $|01\rangle_K$, etc. of this register means oracle's choice $\mathbf{k} = 00$, or $\mathbf{k} = 01$, etc.; of course the state of any register can also be a superposition of sharp quantum states. Register K is only a useful conceptual reference, it provides a panoramic view of the behavior of the quantum algorithm for all the possible oracle's choices. Then there are the two-qubit register X containing the argument \mathbf{x} to query the black box with and the one-qubit register V meant to contain the result of the computation, modulo 2 added to its initial content for logical reversibility. The three registers undergo a unitary evolution, where in particular $\delta(\mathbf{k}, \mathbf{x})$ is computed once. Measuring $[K]$, the content of register K , yields the oracle's choice \mathbf{k} ; this measurement can be performed, indifferently, at the beginning or at the end of the algorithm – which is in fact the identity in the Hilbert space of K . Measuring $[X]$ at the end of the algorithm yields the solution of the problem $\mathbf{x} = \mathbf{k}$.

The initial state of the three registers is:

$$\frac{1}{4\sqrt{2}} (|00\rangle_K + |01\rangle_K + |10\rangle_K + |11\rangle_K) (|00\rangle_X + |01\rangle_X + |10\rangle_X + |11\rangle_X) (|0\rangle_V - |1\rangle_V). \quad (1)$$

Preparing K in a uniform superposition of the four possible oracle's choices provides a panoramic view of the behavior of the quantum algorithm. We can switch to a single choice by measuring $[K]$ in (1), also after having prepared K in a desired sharp quantum state (for uniformity of language, we see a classical preparation of K as a measurement outcome).

State (1) is the input of the computation of $\delta(\mathbf{k}, \mathbf{x})$, which is performed in quantum parallelism on each term of the superposition. E. g. the input term $|01\rangle_K |01\rangle_X |1\rangle_V$ means that the input of the black box is $\mathbf{k} = 01$, $\mathbf{x} = 01$ and that the initial content of register V is 1. The computation yields $\delta(01, 01) = 1$, which modulo 2 added to the initial content of V yields the

output term $-|01\rangle_K |01\rangle_X |0\rangle_V$ (K and X keep the memory of the input for logical reversibility). Similarly, the input term $|01\rangle_K |01\rangle_X |0\rangle_V$ goes into the output term $|01\rangle_K |01\rangle_X |1\rangle_V$. Summing up, $|01\rangle_K |01\rangle_X (|0\rangle_V - |1\rangle_V)$ goes into $-|01\rangle_K |01\rangle_X (|0\rangle_V - |1\rangle_V)$. The computation of $\delta(\mathbf{k}, \mathbf{x})$ inverts the phase of those $|\mathbf{k}\rangle_K |\mathbf{x}\rangle_X (|0\rangle_V - |1\rangle_V)$ where $\mathbf{k} = \mathbf{x}$ and is the identity otherwise. In the overall, it changes (1) into:

$$\frac{1}{4\sqrt{2}} \begin{bmatrix} |00\rangle_K (-|00\rangle_X + |01\rangle_X + |10\rangle_X + |11\rangle_X) + \\ |01\rangle_K (|00\rangle_X - |01\rangle_X + |10\rangle_X + |11\rangle_X) + \\ |10\rangle_K (|00\rangle_X + |01\rangle_X - |10\rangle_X + |11\rangle_X) + \\ |11\rangle_K (|00\rangle_X + |01\rangle_X + |10\rangle_X - |11\rangle_X) \end{bmatrix} (|0\rangle_V - |1\rangle_V), \quad (2)$$

a maximally entangled state where four orthogonal states of K , each corresponding to a single value of \mathbf{k} , are correlated with four orthogonal states of X . This means that the information about the value of \mathbf{k} has propagated to X .

A suitable rotation of the measurement basis of X transforms entanglement between K and X into correlation between the outcomes of measuring their contents, transforming (2) into:

$$\frac{1}{2\sqrt{2}} (|00\rangle_K |00\rangle_X + |01\rangle_K |01\rangle_X + |10\rangle_K |10\rangle_X + |11\rangle_K |11\rangle_X) (|0\rangle_V - |1\rangle_V) \quad (3)$$

The solution is in register X . The oracle's choice has not been performed as yet. It is performed by measuring $[K]$ in, indifferently, (1) or (3). Say that we obtain $\mathbf{k} = 01$. State (3) reduces on

$$\frac{1}{\sqrt{2}} |01\rangle_K |01\rangle_X (|0\rangle_V - |1\rangle_V). \quad (4)$$

Measuring $[X]$ in (4) yields the solution produced by the algorithm, namely the eigenvalue $\mathbf{x} = 01$.

In former work [5], we showed that the quantum algorithm is the sum over the (causal/local) histories of a classical algorithm that knows in advance 50% of the information about the solution. Each history corresponds to a possible way of getting the advanced information (e. g., the algorithm knows in advance that $k_0 = 0$) and to a possible result of computing the missing information (e. g., the algorithm finds that $k_1 = 1$). This decomposition of the quantum algorithm is the generalization of a well known explanation of quantum nonlocality. We mean explaining the correlation between the outcomes of two space-like separated quantum measurements by connecting such outcomes with a causal/local history where causality is allowed to go both forward and backward in time along the time reversible quantum process. The following section provides the perfect classical machine hidden in the quantum algorithm. The classical representation of quantum retrocausation and nonlocality requires mechanical perfection: the hidden machine should be perfectly rigid, accurate, and reversible. That infinite classical precision can be dispensed for by quantization was already noted by Finkelstein [11].

3 Many body interaction analogy

The quantum data base search algorithm hides a perfect classical machine that computes $\delta(\mathbf{k}, \mathbf{x})$ only once (the 2.25 computations on average apply to realistic, imperfect, classical machines). This machine performs a hypothetical many body interaction that is actually a visualization of the behavior of the qubit populations throughout quantum measurement. This many body interaction representation shows that a precondition of the quantum speed up is processing all the information together at the same time.

We start with a representation of classical computation that highlights its two body character. This is Fredkin&Toffoli's billiard ball model of reversible computation [12]. We have a billiard and a set of balls moving and, from time to time, hitting each other or the sides of the billiard, with no dissipation. We should prepare initial ball positions and speeds so that there will be no many body collisions. This is not a problem, it is just an essential feature of the machine: each individual collision is between two balls or a ball and a side. Many body collisions should be avoided because they yield undetermined outcomes – this is the many body problem of course.

Where and when in this situation can we say that any amount of information is processed together at the same time, as assumedly required to explain perception? Outside collisions, the positions and speeds of different balls are processed independently of one another. In collisions, the positions and speeds of two balls are processed together at the same time. However, this joint processing of information never scales up, it is always confined to ball pairs. The information processed together at the same time is the three bits of the input of a universal Boolean gate – represented as a two body interaction by Fredkin's controlled swap gate or Toffoli's controlled-controlled not gate. Of course, parallel computation – several two ball collisions at the same time – does not count since the information is not processed together. Summing up, we should discard classical computation as a model of perception, because the amount of information processed together at the same time is no more than three bits.

The many body problem arises when more than two balls collide together at the same time. The problem is that the outcome of the collision is undetermined. However, this is an idealization; in fact the slightest dispersion in the times of pairwise collisions restores deterministic two body behavior.

Now we describe the perfect classical machine (perfectly rigid, accurate, and reversible) hidden in the quantum database search algorithm – see also [2] and [3]. We represent $\delta(\mathbf{k}, \mathbf{x})$, a function of the binary strings $\mathbf{k} \equiv k_0k_1$ and $\mathbf{x} \equiv x_0x_1$, by the system of Boolean equations

$$\begin{aligned} y_0 &= \sim XOR(k_0, x_0), \\ y_1 &= \sim XOR(k_1, x_1), \\ \delta(\mathbf{k}, \mathbf{x}) &= AND(y_0, y_1), \end{aligned} \tag{5}$$

of truth tables

$$\begin{array}{|c|c|c|c|} \hline & k_0 & x_0 & y_0 \\ \hline C_{00} & 0 & 0 & 1 \\ \hline C_{01} & 0 & 1 & 0 \\ \hline C_{02} & 1 & 0 & 0 \\ \hline C_{03} & 1 & 1 & 1 \\ \hline \end{array}, \quad
\begin{array}{|c|c|c|c|} \hline & k_1 & x_1 & y_1 \\ \hline C_{10} & 0 & 0 & 1 \\ \hline C_{11} & 0 & 1 & 0 \\ \hline C_{12} & 1 & 0 & 0 \\ \hline C_{13} & 1 & 1 & 1 \\ \hline \end{array}, \quad
\begin{array}{|c|c|c|c|} \hline & y_0 & y_1 & \delta \\ \hline C_{20} & 0 & 0 & 0 \\ \hline C_{21} & 0 & 1 & 0 \\ \hline C_{22} & 1 & 0 & 0 \\ \hline C_{23} & 1 & 1 & 1 \\ \hline \end{array}. \quad (6)$$

The C_{ij} ($i = 0, 1, 2, j = 0, 1, 2, 3$) labeling the rows of the truth tables are real non-negative variables. They are the coordinates of the machine parts – our hidden variables. We replace the system of Boolean equations (5) by the following system of equations, representing mechanical constraints between the coordinates of the machine parts,

$$\forall i : Q = \sum_j C_{ij}, \quad Q^\chi = \sum_j C_{ij}^\chi, \quad (7)$$

$$C_{01} + C_{02} = C_{20} + C_{21}, \quad C_{11} + C_{12} = C_{20} + C_{22}, \quad (8)$$

with $\chi > 1$. Q is an auxiliary coordinate. In (7), we can think that left equations are implemented by three differential gears, one for each truth table i . Each gear has one input Q and four outputs $C_{i0}, C_{i1}, C_{i2}, C_{i3}$; right equations are implemented by a similar arrangement with input Q^χ and outputs $C_{i0}^\chi, C_{i1}^\chi, C_{i2}^\chi, C_{i3}^\chi$, obtained from the former coordinates by means of nonlinear transmissions. Equations (8) are implemented by other two differential gears, each with two inputs and two outputs, and the coordinate C_{20} replicated in each gear.

We discuss the behavior of this analog computer assembling it step by step:

1. We start with one of the left equations/gears (7), $Q = \sum_j C_{ij}$, for some value of i . Initially all coordinates are zero. If we push (the part of coordinate) Q , the C_{ij} move to satisfy push and equation. Collisions between bodies are replaced by pushing between parts¹. A push instantly changes the force (or couple) applied to a part from 0 to $\neq 0$. The outcome of this many body interaction is undetermined: for a given Q , there are infinitely many possible "machine movements". We have a many body interaction between 4 machine parts of coordinates C_{ij} – choosing Q as the dependent variable. Since we have to match machine behavior with the transition from state (3) before measurement to one of four possible states after measurement, each occurring with probability $\frac{1}{4}$, we postulate that the probability distribution of the machine movements is symmetrical for the exchange of any two C_{ij} .
2. We add the right equation/gear, $Q^\chi = \sum_j C_{ij}^\chi$, for the same value of i . Now pushing Q can move at most one C_{ij} – C_{ij}^χ movements become mutually exclusive with one another. Perfect coincidence of the times of the

¹Conversely, we could replace the billiard ball model of classical computation by the present model, which can represent both many body and two body interactions.

push exchanged between parts requires perfect rigidity and accuracy of the machine. Flexibility and other imperfections restore deterministic two body behavior, likely with an ordering of pairwise pushes that frustrates the mechanical constraints, thus jamming the machine. For example, if two or more C_{ij} move initially, thanks to a slight deformation of the mechanical constraints, the further movement of Q increases the deformation until the machine jams. No deformation, i. e. machine perfection, implies no jams, namely postulating that one of the C_{ij} moves to satisfy push and equations. Symmetry of the probability distribution yields even probabilities of movement for the C_{ij} . The machine movement produces the Boolean values of the row (of the truth table i) labeled by the one $C_{ij} > 0$.

3. We add the remaining equations/gears. Equations (7) assure that only one C_{ij} moves for each i , equations (8) assure that the C_{ij} that move label the same values of the same Boolean variables, namely that the machine movement satisfies the system of Boolean equations (5).
4. If we push Q , there are 16 mutually exclusive machine movements, corresponding to all the possible ways of satisfying the system of Boolean equations (5). We have a many body interaction between the 8 machine parts of coordinates C_{0j} and C_{1j} , the other coordinates being dependent variables.
5. If we push C_{23} instead of Q , the movement of C_{23} yields $\delta(\mathbf{k}, \mathbf{x}) = 1$. Now there are 4 mutually exclusive machine movements. Each movement produces an oracle's choice and the corresponding solution provided by the second player by means of a single computation of $\delta(\mathbf{k}, \mathbf{x})$ – a single transition $C_{23} = 0 \rightarrow C_{23} > 0$.

This latter many body interaction represents the behavior of the qubit populations throughout quantum measurement. In fact there is an invertible linear relation between the eight $\frac{C_{0j}}{Q}, \frac{C_{1j}}{Q}$ ($j = 0, 1, 2, 3$) and the eight qubit populations. For example, with reference to the reduced density operator of qubit k_0 , let $p_{k_0}^{00}$ be the population of $|0\rangle_{k_0} \langle 0|_{k_0}$, and $p_{k_0}^{11}$ that of $|1\rangle_{k_0} \langle 1|_{k_0}$. By looking at the truth tables, one can see that their relation with the $\frac{C_{ij}}{Q}$ is:

$$p_{k_0}^{00} = \frac{C_{00} + C_{01}}{Q}, \quad p_{k_0}^{11} = \frac{C_{02} + C_{03}}{Q}. \quad (9)$$

The relation for the other qubits, k_1 , x_0 , and x_1 , is derived in a similar way. When all coordinates are 0, all ratios are $\frac{0}{Q}$ and are thus compatible with any value of the populations in the state before measurement. Having postulated a symmetric probability distribution of machine movements sets to $\frac{1}{2}$ the values of the qubit populations before measurement (like in state 3). When $C_{23} > 0$, these ratios become determined and correspond to either 0's or 1's of the populations of the measured observables: the C_{ij} that do not move yield $\frac{C_{ij}}{Q} = 0$, those that move yield $\frac{C_{ij}}{Q} = 1$.

This many body analogy helps to understand what goes on, computationally, in quantum measurement: satisfaction "in one shot" – with a single computation of $\delta(\mathbf{k}, \mathbf{x})$ – of the nonlinear system of Boolean equations constituted by (5) and $\delta(\mathbf{k}, \mathbf{x}) = 1$ (satisfied by pushing C_{23}).

On the contrary, satisfying this system classically, by means of deterministic two body interactions, would require on average, 2.25 computations of $\delta(\mathbf{k}, \mathbf{x})$. More in general, a classical computation satisfies in one shot (i. e. satisfying each gate at the first attempt) a linear Boolean network, in fact through the deterministic propagation of an input into the output. In the case of a nonlinear network, local deterministic satisfaction of gates can be done in several ways, and is likely done in a way that does not satisfy other gates. This leads to trial and error and repeated computations, which yields the relative zero of the quantum speed up.

In the initial state of the quantum algorithm (1), the hidden machine is disassembled and the coordinates of the machine parts are independent of one another. Correspondingly the quantum state is factorizable – quantum measurement of the register contents would yield uncorrelated outcomes.

The unitary part of the quantum algorithm, yielding state (3), assembles the machine: all parts – in the configuration all coordinates zero – get geared together in a non-functional relation (established by equations 7, 8). Correspondingly the quantum state is entangled. Measuring the register contents in this state corresponds to operating the machine – to pushing C_{23} . This generates the interaction that in one shot produces the oracle's choice, runs the algorithm, and produces the solution.

This many body analogy can easily be generalized.

If several function evaluations are required, like in data base search with $N > 4$, just one computation of $\delta(\mathbf{k}, \mathbf{x})$ and one rotation of the X basis creates the superposition of a state of maximal entanglement between K and X (corresponding to the assembled machine) and the factorizable initial state back again [4], [5] (corresponding to the disassembled machine). Iterating these operations $O(\sqrt{N})$ times "pumps" the amplitude of the entangled state to about 1. Measurement should be performed – the machine operated – in this final state.

In the other quantum algorithms, the oracle chooses a function $f_{\mathbf{k}}(x)$ out of a known set of functions and gives to the second player the black box for its computation. The second player should find out a certain property of the function (e. g. its period) by means of one computation of $f_{\mathbf{k}}(x)$ – against, classically, a number of computations exponential in the size of the argument. It is sufficient to: (i) represent the oracle's choice and the property of the function as a network of Boolean gates, with the rows of the truth tables labeled by the hidden variables, (ii) introduce the equivalent system of equations on the qubit populations (iii) assemble the perfect machine through the unitary evolution part of the quantum algorithm, and (iv) operate it by measuring the register contents. Quantum measurement satisfies in one shot a nonlinear Boolean network.

4 Interdisciplinary implications

The notion that a quantum algorithm knows in advance 50% of the solution it will find in the future, and the related notion of satisfying in one shot a nonlinear Boolean network, interplay with a variety of scientific and philosophical issues. In the following, we call the many body interaction hidden in the measurement stage of the quantum algorithms *simultaneous computation*.

Among the scientific issues, we find:

- The character of visual perception implies the capability of processing together at the same time a significant amount of information. Simultaneous computation can process in this way any amount of information, therefore it can be the physical computation basis of perception. Classical computation, capable of processing together at the same time no more than three bits, could not.
- Simultaneous computation provides a formalization of the physical computation level of those neurophysiological and physical theories that place consciousness in quantum measurement, like Hameroff&Penrose's orchestrated objective reduction theory [16], [17], [18] and Stapp's theory [25].
- Let us adopt the strong artificial intelligence (AI) assumption that a state of consciousness is a computation process with an upper bound to the number of computation steps, thus representable as the process of satisfying a Boolean network. In the present perspective, the entire computation should be performed in one shot, together at the same time, by quantum measurement. To match subjective experience, the computation should represent the feeling of self, memories, emotion, thinking, sensorial information, etc. Most of the processing (e. g. the feeling of self) would be repeated at each successive measurement; part of the processing would be updated to track changes – in memories, emotions, etc. A frequency of 50 measurements per second (50 "frames per second"), could cope with our rates of change.
- Simultaneous computation solves – at the physical computation level – the "hard problem" pinpointed by Chalmers [7]: explaining how disparate informations can come together in the unity of subjective experience – this unity is processing together at the same time all information.
- A qualia is an atomic sensation – apparently without an internal logical structure – like that of "redness" – see Ref. [22]. Classical computation is phenomenological in character, feeling a qualia would correspond to an algorithm that behaves consistently with that feeling (talking of the red color, stopping at a red light). In the context of quantum simultaneous computation, "seeing", or "feeling", are synonyms of "measuring". Feeling a qualia could correspond to measuring some fundamental observable (and, at the same time, the self – possibly comprising other qualia – and some relation between feeling of self and the feeling of a color).

- Identifying consciousness with simultaneous computation – i. e. the mechanism enabling the quantum speed up – gives quantum consciousness a potential evolutionary advantage over a classical consciousness. The former could be immensely quicker and/or leaner in computational resources in tasks essential for survival. With respect to classical computation, quantum associative memory requires an exponentially lower number of artificial neurons [28], quantum pattern recognition can be traced back to quantum data base search, which yields a quadratic speed up [27], [30], quantum machine learning has recently been shown to be substantially faster [20].
- Teleological evolutions often explain organic behavior better than deterministic classical evolutions – see Ref. [13]. However, such explanations are generally considered to be phenomenological in character, because of the belief that, really, evolutions could not be driven by final conditions. Quantum algorithms, being partly driven by their future outcome, provide well formalized examples of teleological evolutions.
- Stapp's theory relies on the quantum Zeno effect and lives with decoherence – see Ref. [25]. The present model suffers decoherence exactly as quantum computation does, which means very much. This divergence could mean cross fertilization. It puts emphasis on the quantum information approach of driving the state of the computer registers by means of the Zeno effect – see Ref. [22].
- The notion that quantum algorithms are partly driven by their future outcome is consistent with Sheehan's retrocausation theory and critical revision of the notions of time and causality in physics – see Ref. [23].

Among the philosophical issues, we find:

- Being entirely driven by past conditions excludes free will, as well as being entirely driven by future conditions. Being partly driven by either condition – like quantum algorithms – leaves room for freedom. In quantum algorithms, freedom from determinism is nondeterministic computation – capability of satisfying in one shot a nonlinear Boolean network.
- A quantum algorithm, for the fact of knowing in advance 50% of the solution it will find in the future, "exists" in an extended present. This suggests that our existence is not confined to the instantaneous present we normally experience. With reference to Indian philosophy, the experience of an instantaneous present would be illusory, the timeless reality experienced in Moksa (in western language, in special "altered states of consciousness" – see Ref. [8]) objective.
- Insight – understanding an even immensely complex structure in one instant – seems to be a most evident experience of simultaneous computation.

- Simultaneous computation has an upper bound to the number of computation steps, like quantum algorithms and AI. This is a limitation with respect to Lucas-Penrose's argument that consciousness – being able to "see" Gödel's theorems – is not confined to finitistic computation – see Ref. [19], [21]. As for the possibility of extending simultaneous computation to denumerably infinite Boolean networks, see Ref. [6].
- Mind-body duality, or the duality between a perfect world of ideas and an imperfect material world, here becomes the duality between (i) perfect/nondeterministic classical machines (hidden in quantum measurement), yielding a speed up and capable of processing any amount of information together at the same time, thus of hosting consciousness, and (ii) imperfect/deterministic classical machines, capable of processing no more than three bits together at the same time, incapable of hosting consciousness. This also matches with Stapp's distinction between the mind and the rock aspect of quanta [25]. If there is only quantum physics, this duality vanishes. The perfect/nondeterministic side would be objective, the other side phenomenological or illusory.

5 Conclusions

The advanced knowledge of the solution, which explains the quantum speed up, has been seen as a many body interaction between the parts of a perfect classical machine whose coordinates represent the qubit populations throughout quantum measurement. In one shot (with a single input-output transformation of each gate), this interaction senses and satisfies all the gates of a nonlinear Boolean network together at the same time.

In contrast, the amount of information processed together at the same time by classical computation is limited to the three bit input of a single universal Boolean gate – many such gates in parallel do not count since the information is not processed together. Correspondingly, classical computation cannot satisfy a nonlinear Boolean network in one shot (but for a very lucky instance).

Simultaneous computation answers our prerequisite for the physical computation level of perception – capability of processing any amount of information together at the same time. With reference to the theories that place consciousness in quantum measurement, simultaneous computation takes two pigeons with one stone:

1. it formalizes the physical computation level of these theories,
2. in such a way that the fundamental mechanism of consciousness is the same of the quantum speed up.

The overall result is giving quantum consciousness, with respect to classical consciousness, a potentially enormous evolutionary advantage.

More in general, simultaneous computation could be the physical computation level of biological information processing. It provides a scientific ground

to teleological explanations of organic behavior and a possible answer to long standing philosophical questions.

The assumption that biological computation is simultaneous computation implies that the brain hosts a sufficient quantum coherence – see Ref. [10], [15], [25], [26], [29]. It can be argued that the problem of decoherence is common to quantum information, whose alleged advantage – possibility of working close to 0 Kelvin and without hydrophobic pressure – is frustrated by the fact that the size of the computation cannot scale up in any conceivable way. Our biased opinion is that the top level evidence that the mind is quantum, and cannot be classical, is strong enough to look for a common solution. Tackling the problem of decoherence from the two leads – quantum information and biological – might yield cross fertilization.

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